Airborne laser scanning (lidar), prospection and modelling the Irish archaeological landscape

2. Airborne laser scanning (lidar),[1] prospection and modelling in the Irish archaeological landscape

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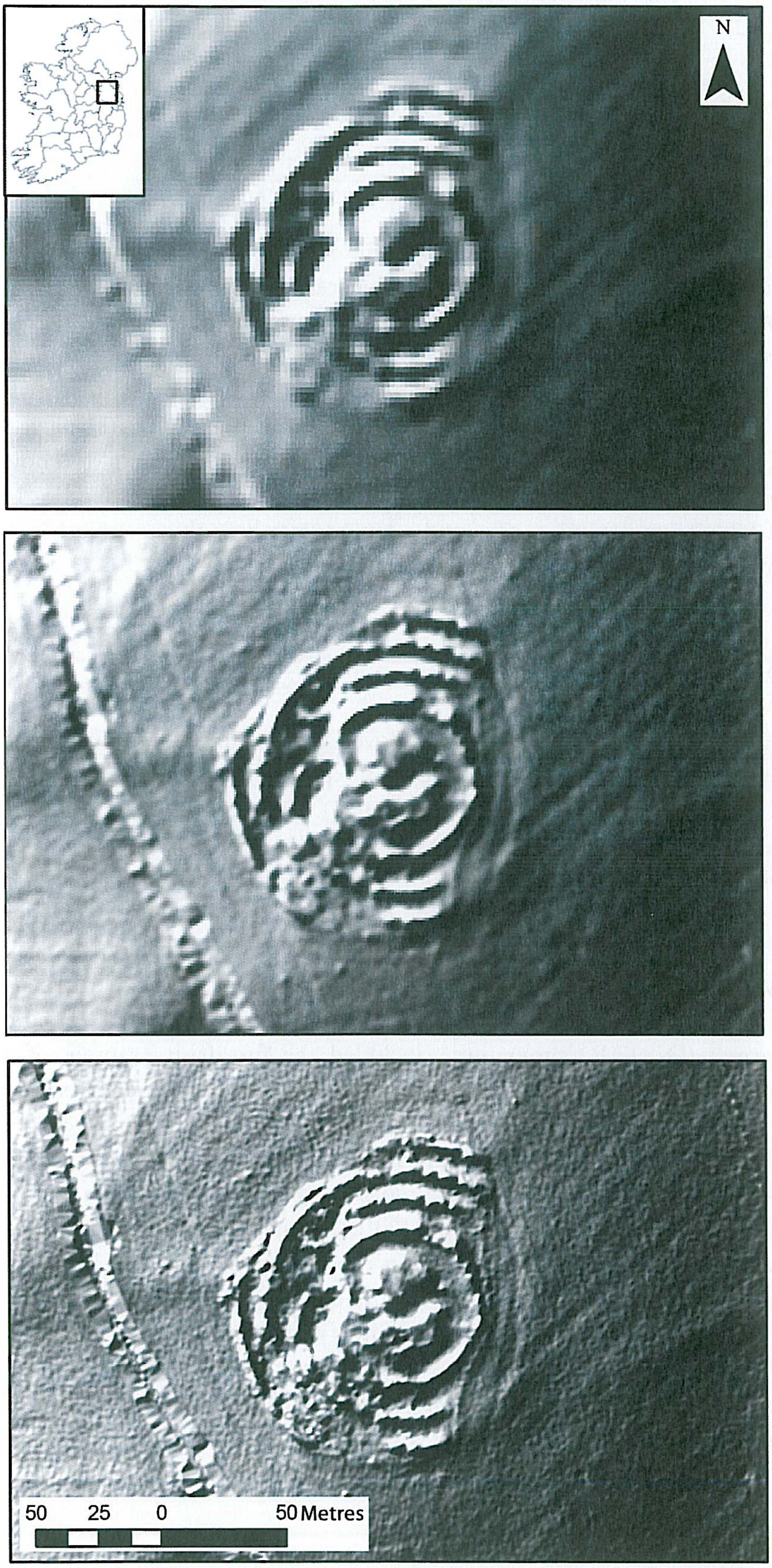
Light Detection and Ranging (hereafter lidar) has become an increasingly popular tool for remote archaeological prospection over the last decade. Lidar uses lasers to record the three-dimensional location of points. There are two main ways of capturing lidar data: terrestrial scanning, where points are recorded from a static scanner, and Airborne Laser Scanning (hereafter ALS), where the scanning apparatus is connected to an aircraft. The terrestrial technique is called 3D scanning and is discussed elsewhere in this publication (Hanley & Barrett, this volume). The aerial approach is the subject of this paper, which explores how ALS has been used in archaeological prospection in Ireland over the last decade. In addition, a series of Irish examples and a case-study demonstrate how this technique can best be used in current and future archaeological projects.

A brief history of ALS in Irish archaeology

ALS has been used to explore the Irish landscape for over 10 years. In 2004 a team from the University of Cambridge employed airborne lidar to explore the Lough Crew passage tomb complex in County Meath (Shell & Roughley 2004). This ground-breaking study was one of the earliest archaeological landscape ALS surveys in Europe. Subsequent projects pioneered by the Discovery Programme (a public institution for advanced research in Irish archaeology) included a high-resolution survey of the Hill of Tara, Co. Meath (Corns et al. 2008), and, more recently, the UNESCO World Heritage Site (WHS) of Skellig Michael, Co. Kerry. The Boyne Catchment GIS (Geographic Information System) of the Brú na Bóinne WHS in County Meath, funded through the Irish National Strategic Archaeological Research (INSTAR) programme, included the first Irish example of a systematic archaeological survey using ALS in 2011. This ALS survey identified over 100 potential new sites in and around the WHS, using a range of visualisation techniques (see below) (Davis et al. 2013; Megarry & Davis 2013, 81–91). Davis (2011) also investigated how ALS can be used to explore landscape and site morphology in County Meath.

Landscape is a complex concept, defined both by its contemporary inhabitants and by the totality of historical processes which have shaped its modern appearance. The long and deep history of the Irish landscape is etched on its surface like a palimpsest, and these scratches and scrapes often testify to processes and activities not recorded in the historical record. ALS enables us to interrogate these activities by capturing the often subtle variations in the landscape that are invisible from the surface. It provides a hyper-real perspective of topography, where things not usually visible to the naked eye can be seen in clear detail,

[1] The term 'Airborne Laser Scanning' is now favoured when discussing airborne lidar, and the lower-case spelling 'lidar' is preferred to the traditional 'LiDAR' (see Opitz & Cowley 2013).



Illus. 1—Comparison of datasets at different resolutions on the Hill of Tara, Co. Meath (ALS from Ordnance Survey Ireland).

giving great investigative control to the viewer and providing a diachronic snapshot of the complexity of landscape. While ALS can be invaluable in certain situations, it can be better applied to some studies than to others. It should not be a replacement for other remote sensing techniques and is best used as part of a range of data, including aerial photography, geophysical survey and Ordnance Survey mapping.

ALS collection and processing

ALS records the range or elevation of a target from an aircraft and then georeferences these data using a Global Positioning System (GPS). It is capable of capturing many high-resolution points in a short space of time. Traditionally, ALS returns three values: an easting, a northing and an elevation. The elevation value captures the changing landscape terrain in great detail, including earthworks and other extant archaeological features. In their basic form, ALS data provide a gazetteer of values representing geographical coordinates and elevation. These data are recorded in points that are used to create a Digital Elevation Model (DEM) of the landscape, which can then be manipulated in a GIS. This DEM forms the basis of archaeological survey and prospection.

Returns and resolution

The detail recorded in ALS depends on its resolution. This is defined by a number of factors, including the landscape in question, the ability of the scanning equipment to capture many points quickly and the post-capture processing. Typical ALS resolution varies between 2 m (a point every 2 m) and 25 cm, but it is possible to process ground surfaces at even finer resolutions. Higher-resolution datasets usually capture more surface detail, but they necessitate far greater processing and often cost considerably more than lower-resolution data (Illus. 1). The optimal resolution of ALS data will depend on a number of factors, including project aims, budget and computational abilities. But lower-resolution datasets should not be discounted prematurely, especially in an Irish context, where many sites retain substantial surface signatures as earthworks.

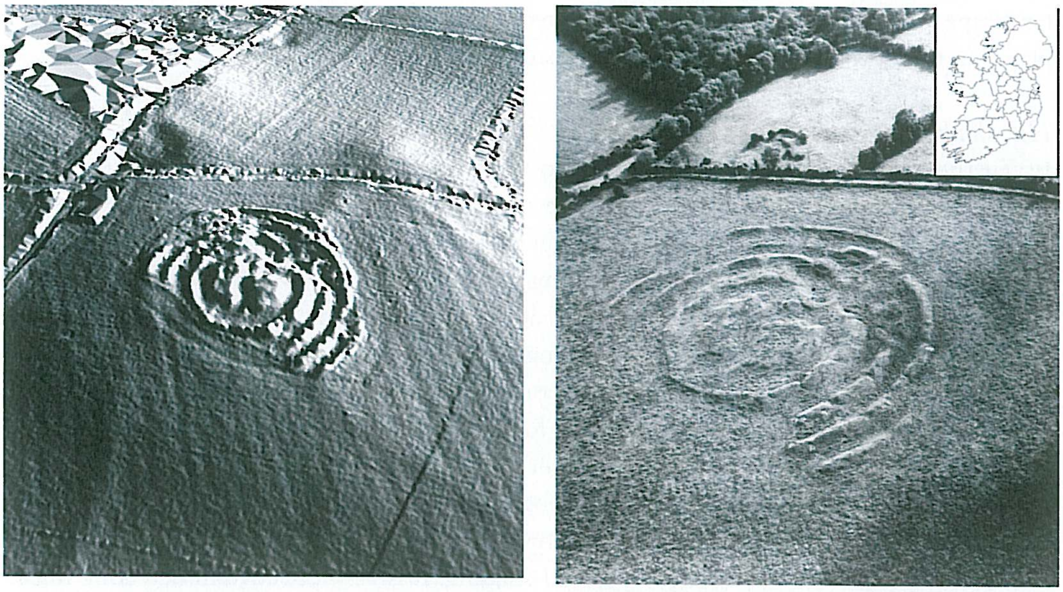
ALS is also capable of penetrating light vegetation and capturing the underlying physical topography of the landscape. Prior to recording the ground surface, the pulse from the scanner is returned numerous times as it meets resistance from branches and leaves (Illus. 2). As vegetation density and foliage can affect the strength and number of the returning pulses, ASL, while excellent in areas with light vegetation, is not suitable for densely forested areas (like coniferous plantation) and is usually flown in other landscapes between late autumn and early spring. In Europe, this ability to penetrate lighter vegetation has made ALS very popular in large forested regions where field survey would be very time-consuming or in places where extensive earthworks are present but difficult to record (Doneus et al. 2008).

ALS visualisation techniques and modelling tools

ALS and traditional aerial photography

The value of oblique aerial photography has long been understood by Irish archaeologists.

Illus. 2—Example of ALS penetrating vegetation in County Leitrim (ALS commissioned by Leitrim County Council; aerial photography from Ordnance Survey Ireland).



Illus. 3—Comparison of oblique aerial photo and ALS survey at the Hill of Ward, Co. Meath (ALS from Ordnance Survey Ireland; aerial photography from Cambridge University Collection of Aerial Photography).

Early projects yielded stunning results by focusing on well-known earthen monuments (Raftery 1944). When reviewing these images in 1969, Norman and St Joseph (1969, 1) noted how 'careful attention has to be paid to lighting if the work is to yield best results. Few buried sites were illustrated as if the conditions favouring their discovery, largely determined by the vagaries of Irish weather, were not then sufficiently understood.' Subsequent projects took account of the unique challenges posed by the Irish climate, but photographers were still dependent on lighting conditions dictated by the inclination of the sun at certain times of the day.

When processing ALS data, lighting and inclination are modelled using a GIS. While aerial photography captures the shade or colour of the landscape, ALS focuses solely on elevation. By varying artificial lighting angles and shading it can provide a sense of depth and variation similar to early black-and-white oblique photos but rarely visible in vertical aerial imagery (Illus. 3). It is also becoming common practice to capture intensity data from the scan. These record the rate of absorption of the laser by the surface it hits. They reflect factors like water density and plant health, potentially indicating subsurface archaeology (for more information see Challis et al. 2011).

Using a GIS, it is possible to generate images and surfaces from the ALS data which emphasise or even exaggerate archaeological features. (Some of these surfaces are further explored in the following sections.) There are two primary means by which this is achieved. The first is by the application of visualisation techniques that use solar illumination to highlight low-lying features. The second employs statistical modelling, which emphasises local differences in the landscape by removing topographical variables like slope. In such cases slope is removed, highlighting sheer features like banks or ditches. Given the aforementioned uniqueness of the Irish climate and landscape, it is unsurprising that certain visualisation techniques and statistical models are more effective for archaeological prospection than others. Factors including relief and topography, the ruggedness of the landscape and the character of the archaeological remains are taken into account in planning the optimum approach to such a survey.

Hill-shading and illumination techniques

By far the most common technique used to visualise the results of ALS is the hill-shading model, which models the shadows cast across the landscape from a light source. The angle and inclination of the light source can be set in a GIS and it is also possible to exaggerate the underlying topography, thereby casting deeper shadows. This technique is highly effective in highlighting subtle landscape features, but can sometimes cause confusion in more complex situations by over-emphasising background features like moraines or eskers. In such cases it can be useful to run some basic statistical tools that can help to differentiate the man-made from the natural (see below for more detail).

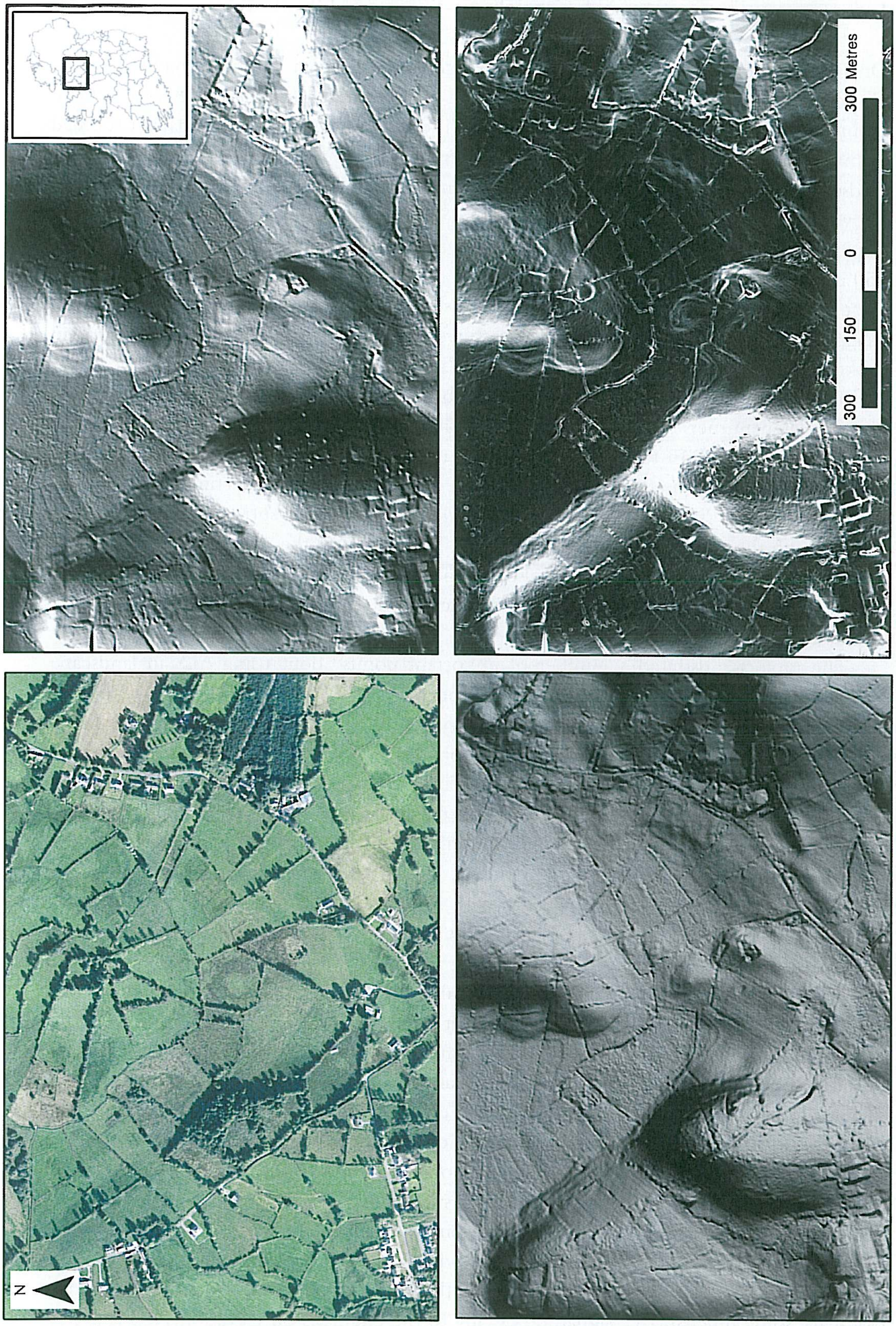
One of the great advantages of ALS over traditional oblique aerial imagery is that the user gets to choose the lighting. It is also possible to model hyper-real lighting situations, such as illuminating the landscape from more than one direction using multiple sources. This technique is called multidirectional hill-shading. It is very effective in detecting linear earthworks, for example, which can be easily missed in single-direction models owing to a similar orientation to the light source. It is possible to create combined hill-shade models with shadows cast from over sixteen directions (Illus. 4).

Solar illumination is another lighting technique developed to identify subtle linear archaeological features. While hill-shading explores how shadows are cast on the landscape, solar illumination explores the amount of light that touches parts of the landscape. Given the upstanding—albeit subtle—nature of archaeological features, light touches them from more angles than it touches flat ground. This tool is called the sky-view factor and can be downloaded as a GIS tool (Kokalj et al. 2011).

Analytical and statistical modelling techniques

While hill-shade models remain the most effective way to identify archaeological sites using ALS, there are some landscapes where these approaches are less effective. In these cases, using other landscape surfaces like slope, which can be made from the original elevation model, can be effective. Slope is defined as the maximum rate of elevation change between two points. Since archaeological sites manifest themselves as slight changes in elevation, slope models can be used to detect these changes. Alongside vertical exaggeration, slope models are a very effective way of identifying sites, especially if localised colour schemes are used. Similar tools can be used to explore the aspect or orientation of the landscape, or the curvature of the topography. In some cases these surfaces can highlight variations that correspond to archaeological sites.

In lower-relief landscapes it may be necessary to apply more complex modelling techniques to identify very low-lying sites or features. There are a wide range of statistical tools that can identify patterns in ALS data. In most cases these tools aim to emphasise archaeological features by differentiating them from natural changes in the landscape, like slopes or river-banks. This leaves only unexpected values, which often represent archaeology. Local relief modelling is a technique which assesses the expected terrain of the landscape and then subtracts this model from the actual landscape. By doing this it produces a model that only shows local variations, which is especially effective in identifying mounds and earthworks (Hesse 2010).



Illus. 4—Different visualisation techniques used in the N4 ALS study (Leitrim). Aerial photograph (top left); single-direction hill-shade (top right); multidirectional hill-shade (bottom left); and slope map (bottom right) (ALS commissioned by Leitrim County Council; aerial photography from Ordnance Survey Ireland).

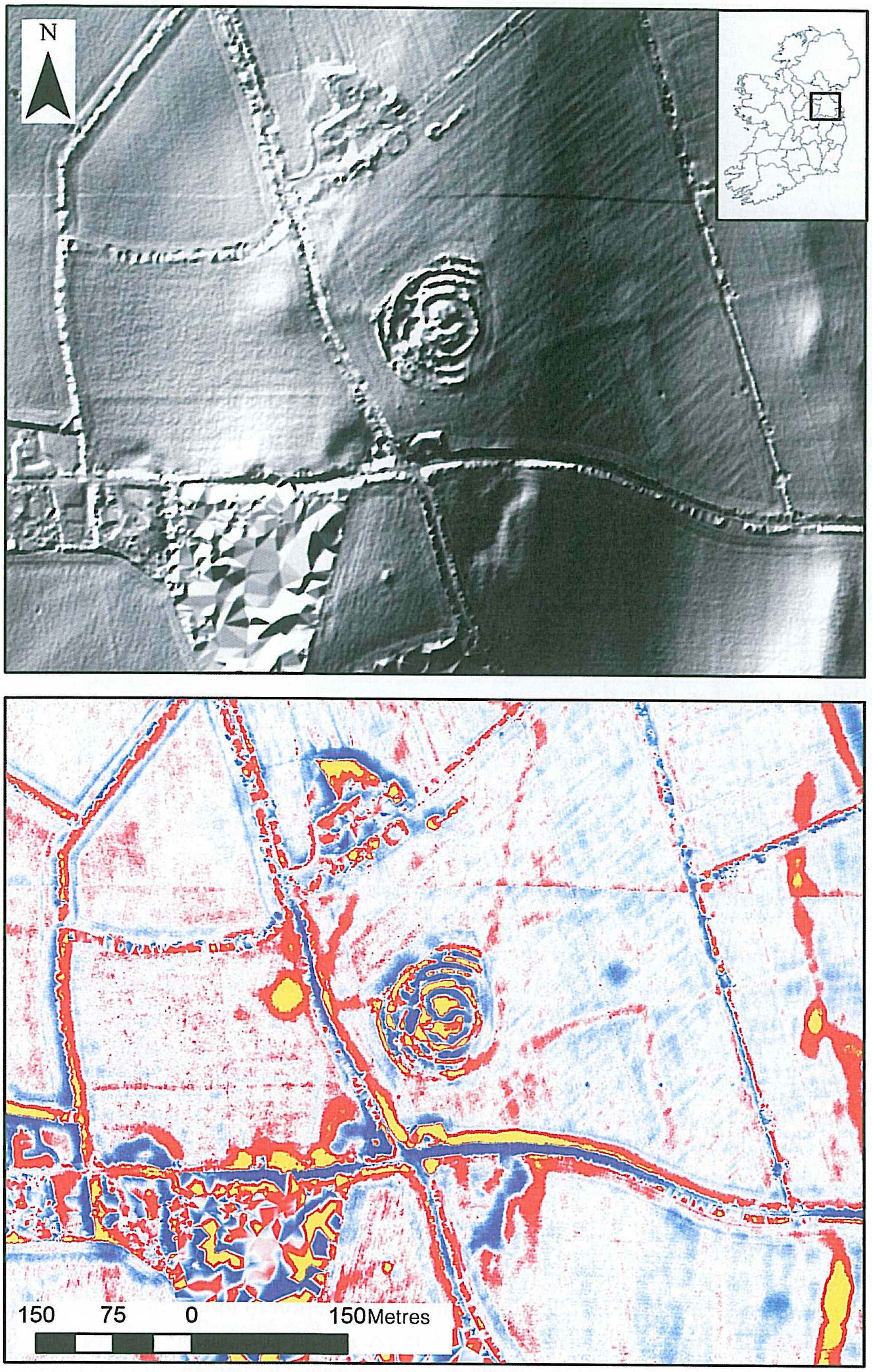
Lidar survey in practice: N4 Carrick-on-Shannon–Dromod

During the planning of the proposed N4 Carrick-on-Shannon–Dromod road scheme in County Leitrim, an ALS study was conducted by the author for the NRA and Leitrim County Council (Megarry 2011). This project used a 2-m-resolution lidar dataset sourced from Ordnance Survey Ireland and converted it into a digital surface model of the landscape, alongside vertical and oblique aerial imagery, modern and historical mapping and known archaeological site locations (from the Sites and Monuments Record). A series of distance buffers were generated at 50-m increments, delineating areas within 50 m, 100 m, 150 m and 200 m of the proposed route, and a number of ground surfaces were generated for prospective purposes. These included hill-shades from multiple directions and some exaggerated elevation models (Illus. 5), which were investigated against the aforementioned background datasets for evidence of previously unknown archaeological sites.

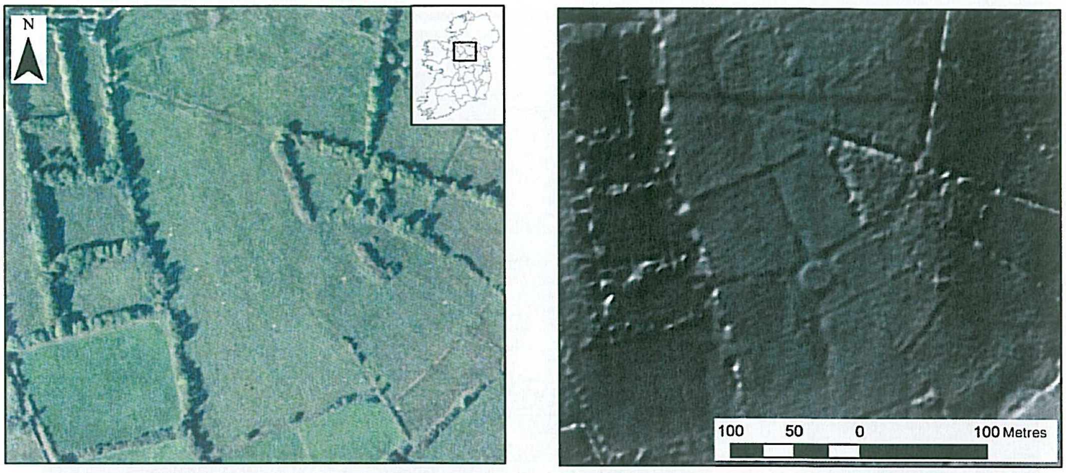
This protocol was applied on a townland-by-townland basis; potential new sites were given an alphanumeric designation based on their townland and the sequence in which they were identified. In total, twelve potential new sites were identified within 100 m of the proposed route. The 2-m dataset was particularly effective in detecting larger circular features (probable ringforts and embanked enclosures), with the surface model recording sites beneath the region's light foliage (Illus. 6). In many cases the surface models not only identified potential new sites but also provided a landscape context for previously documented sites, such as identifying field systems around ringforts and large earthworks enclosing smaller ringforts.

The project illustrated a number of important points about using ALS in landscape survey. First, it highlighted the efficacy of the technique, even in marginal landscapes traditionally deemed unsuitable for desktop survey using remotely sensed data like ALS or satellite imagery, owing to environmental factors like drainage. While ALS can struggle to get clear readings in such environments—and fails entirely when dealing with waterlogged landscapes containing standing water—there is enough variation in the landscape to make the technique both informative and rewarding. Second, the N4 project illustrated the benefit of using quite coarse resolution data. There is a tendency amongst some ALS practitioners to equate resolution quality with results; it is clear, however, from the case-study that 2-m-resolution data were sufficient to detect large landscape features with a strong degree of certainty.

While such survey can yield significant results, archaeological practitioners are rarely in a position to dictate the terms of data capture or even processing. Commissioning ALS data is often too expensive for archaeological companies, but they are often obtained for design purposes by engineers or councils in the planning phases of a project. Archaeologists therefore have to use what is available, and the evidence from the N4 project suggests that even coarse data produce valuable results. Conversely, ALS cannot detect everything, especially in marginal environments such as flooded wetlands. There is a substantial benefit to be gained from using different data sources, such as vertical aerial photographs, modern and historical maps, geophysical survey and even satellite imagery, where available, within a GIS. On a less technical level, it is important—where possible—to check the results through field survey incorporating local knowledge of the landscape. ALS can only detect features that leave some relief surface signature. Owing to the emphasis on elevation, ALS is better at detecting some site types (like ringforts, embankments and passage tombs or mounds)



Illus. 5—Local relief model of the Hill of Ward (after Hesse 2010; ALS from Ordnance Survey Ireland).



Illus. 6—Ringfort and field system identified during the N4 ALS study (ALS commissioned by Leitrim County Council; aerial photography from Ordnance Survey Ireland).

than others (*fulachtaí fia*/burnt mounds, post-holes and ditches) which leave no surface signature.

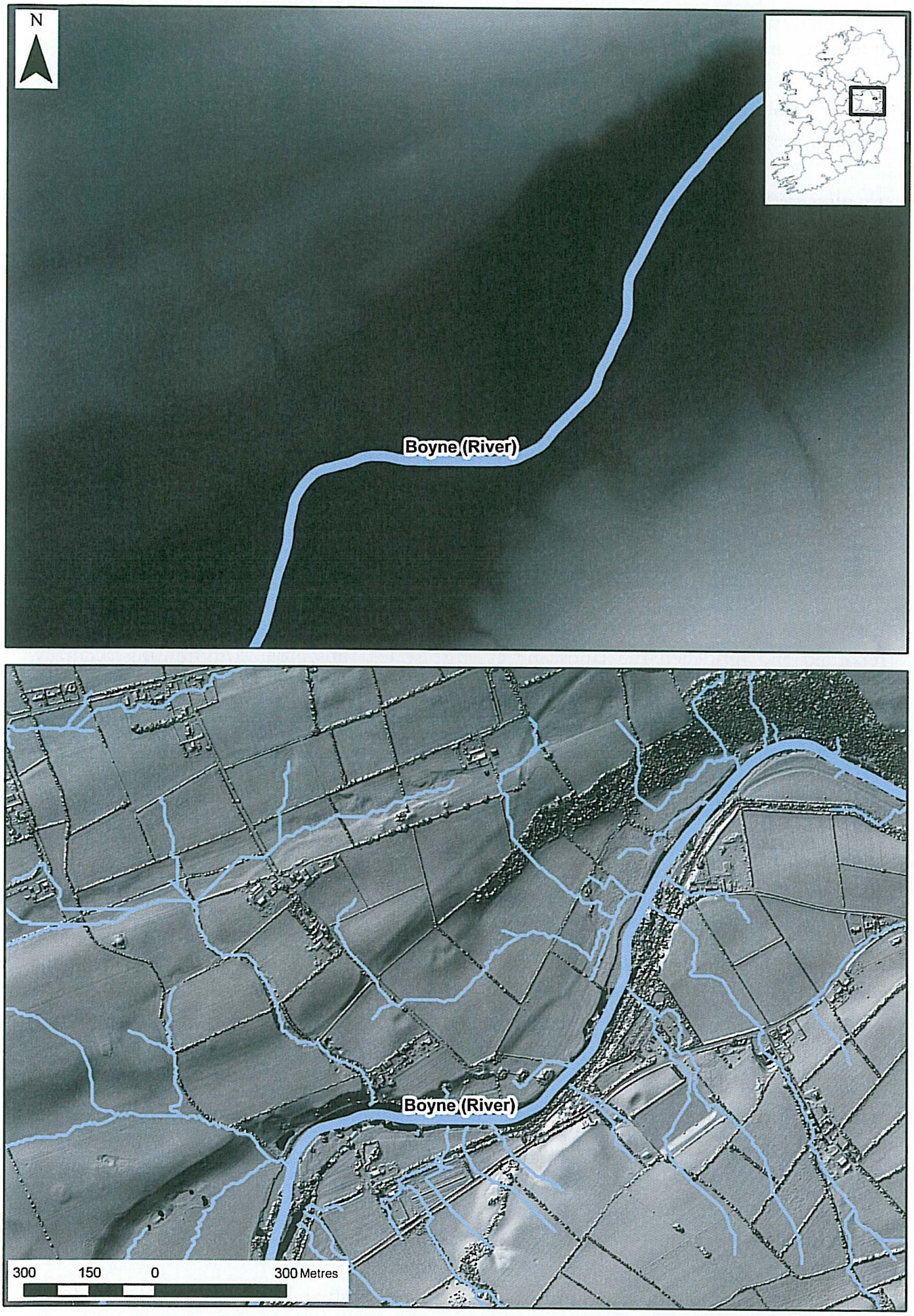
Whither now for lidar data?

ALS provides a hyper-real view of the landscape, yielding previously unavailable information about site layout and landscape topography. While it is becoming an increasingly popular and affordable tool for archaeological site prospection, it has many other uses. The surface models generated for site identification are derived from an underlying surface model that records the elevation values of the landscape topography. These values—and their derivatives such as slope, aspect, etc.—can be used to explore questions of human–environment interaction at a previously unavailable scale. Advances in computing now allow us not only to view but also to model high-resolution datasets.

The remainder of this paper will briefly explore two such applications which can have considerable influence on planning and the mitigation of development impacts on archaeological landscapes: hydrological modelling and landscape prominence. Examples will be taken from 1-m ALS datasets of the Brú na Bóinne WHS. These data have been the subject of much study, centred on the INSTAR-funded project between 2008 and 2011 (for more information see Davis et al. 2010).

Hydrological modelling

ALS has been extensively used for flood-risk mapping. Coastal and riverine environments prone to water-level change can be mapped in high resolution to model the effect of rising flood waters. Basic tools are available in most GIS programmes to explore river catchments, watershed boundaries and drainage points in the landscape. The benefits of such models to archaeology are numerous. Many archaeological sites were concentrated on or in close proximity to water sources and rivers on alluvium or gley soils laid down by flood waters. Traditional hydrological models were only as good as the underlying dataset and so could



Illus. 7—Hydrological modelling in the Brú na Bóinne World Heritage Site, showing 1-m ALS DEM (above) and stream network modelled from DEM over 1-m hill-shade model (below) (ALS commissioned by Meath County Council).

only identify streams and watersheds on a regional scale. ALS enables us to explore these questions in far greater detail, depicting seasonal streams and local watersheds. A comparison of hydrological modelling of river and stream beds is shown in Illus. 7. The greater resolution of the ALS dataset allows for substantially more detail in the model, detecting seasonal channels alongside perennial streams.

Prominence in the landscape

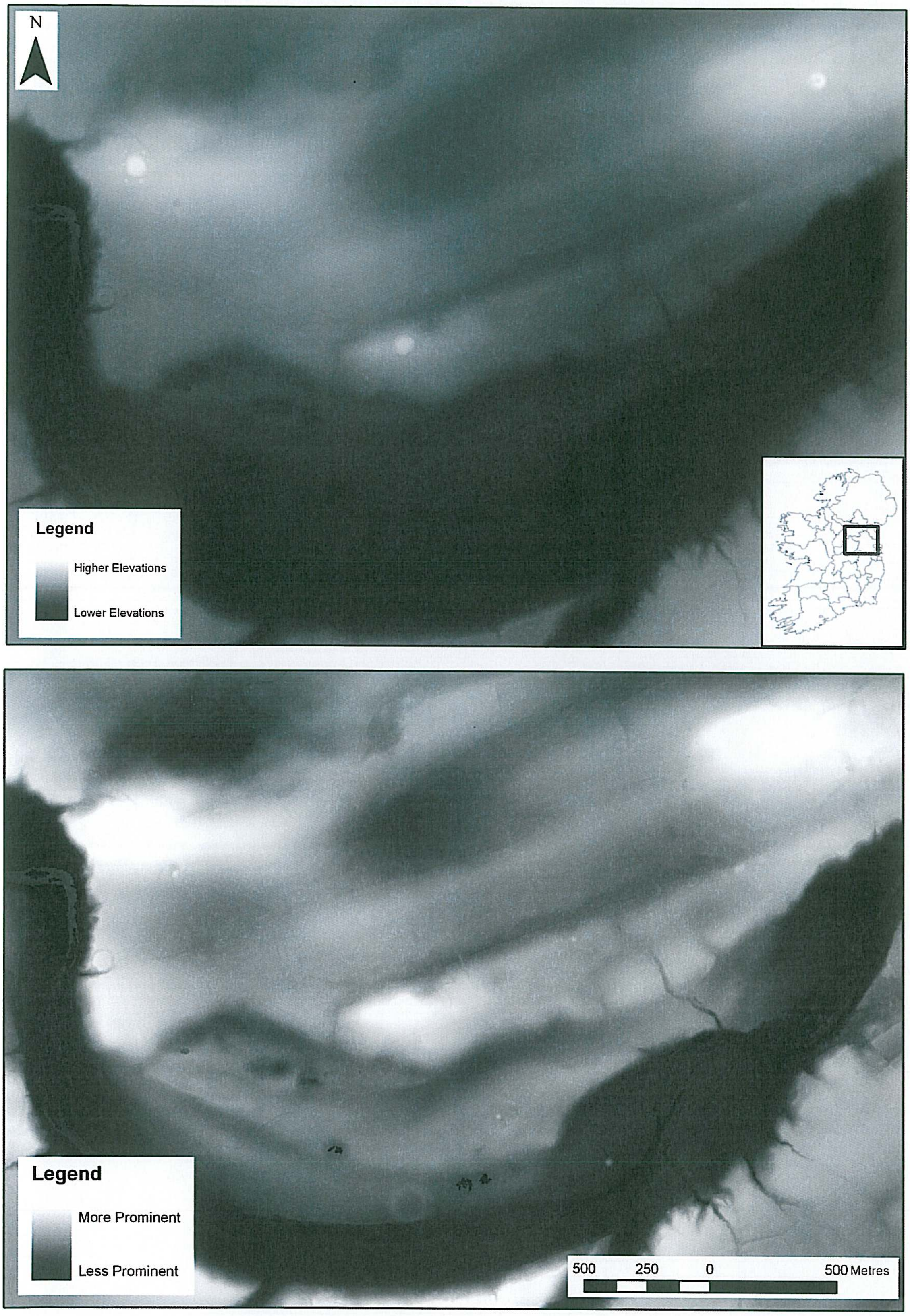
High-resolution elevation datasets can be used to generate very accurate viewsheds (the extent of the view) from single or multiple points in the landscape. Such detailed viewsheds were previously impossible to produce owing to computational restraints but are now possible with relative ease using a GIS. While such a tool can be useful to explore the visual impact of development construction in a landscape or to investigate questions of perception in past societies, they are still restricted to examining a limited number of points rather than the entire landscape. The ideal solution to this issue would be to generate what is known as a total viewshed, where viewsheds are calculated from every point in the landscape. This task would be computationally intensive and time-consuming, especially when dealing with the high-resolution datasets produced by ALS.

A far simpler approach is to explore the prominence of the landscape. Llobera (2001, 1007) describes topographical prominence as 'a function of height differential between an individual and his/her surroundings as apprehended from the individual's point of view'. Early studies in viewshed and prominence were hindered by coarse elevation datasets which recorded and modelled the landscape at large scales, substantially minimising accuracy, especially when exploring local visual and topographical dynamics. ALS now provides elevation data at a resolution sympathetic to the individual, enabling studies of visual perception and topographical prominence at an appropriate scale.

Topographical prominence is calculated by ascertaining the height difference between each point in the landscape and the average height of the surrounding area within a defined radius. As such, each location in a landscape is deemed to be above the average height (prominent) or below the average height (inconspicuous) of the study area. Illustration 8 shows an area at the centre of the Brú na Bóinne WHS, focusing on the great tumulus at Newgrange. It depicts the elevation of the shale ridges running through the WHS (left) and the topographic prominence of the tumulus location (right). It is clear that while the topographic situation of Newgrange is elevated, it is also very prominent. Perhaps more interesting is the prominence of points around the tumulus which do not have such high elevations. It would be easy to overlook such places in favour of higher locations. Understanding prominence has obvious implications in development planning and landscape management and ALS allows us to explore the dynamic on a human scale, sympathetic to local concerns and interests.

Conclusions

This paper has explored the application of ALS to the Irish archaeological landscape. It has explored different visualisation techniques, focusing specifically on solar shading and illumination, and statistical modelling used to highlight archaeological features in the landscape. It has presented results from an ALS survey undertaken in 2011 along the route



Illus 8—Llobera's prominence model, showing the elevation of Newgrange, Co. Meath (above), and its topographic prominence (below) (ALS commissioned by Meath County Council).

As a matter of interest what does this actually show?

of the proposed N4 Carrick-on-Shannon–Dromod road scheme showing the efficacy of ALS, even when using a coarse dataset in a marginal and often waterlogged landscape. It has also highlighted potential problems with using ALS data and has stressed the importance of using other datasets alongside ALS models. Finally, it explored the novel applications of hydrological modelling and topographical prominence using analytical tools available in most GIS programmes. In conclusion, it has shown that ALS data can be used for far more than just archaeological prospection and can provide information about the archaeological landscape at a human scale.